FLIGHT RESEARCH TECHNIQUES UTILIZING REMOTELY PILOTED RESEARCH VEHICLES

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SUMMARY

This lecture presents a survey of the use of the remotely piloted research vehicle (RPRV) in aeronautical research. The paper emphasizes the flight test experience that has been acquired at the NASA Dryden Flight Research Center with several types of RPRV's, including those with a pilot in the loop, a concept developed at Dryden. The paper discusses the application of RPRV's to various test objectives: the approaches utilized range from the simplest and least expensive of vehicles, such as the Minisniffer, to the very sophisticated and complex highly maneuverable aircraft technology (HiMAT) RPRV.

The advantages and disadvantages of RPRV's are discussed, as well as safety considerations. The ground rules set early in a program can profoundly affect program cost effectiveness and timeliness.

1.0 INTRODUCTION

Experiments in remotely piloted vehicle (RPV) flight testing began at the NASA Dryden Flight Research Center approximately 10 years ago. Those early tests started by adding a test pilot and digital computer elements to state-of-the-art drone technology. Each succeeding RPV program made greater use of these elements in meeting research objectives.

The RPRV (the word research was first added to RPV in Ref (1)) became increasingly popular with NASA engineers and program managers because of its greater flexibility and because they had greater control over what the aircraft did in flight. This control was achieved from an aircraft-type cockpit that was on the ground and incorporated a full instrument flight rules (IFR) panel, a forward-looking TV, and variable stick-force gradients. A programmable ground computer functioned as a part of an experimental aircraft control system. The RPRV was less popular with NASA test pilots, on the other hand, because they had fewer opportunities to fly RPRV's and because more simulation time was necessary to prepare for flying RPRV's. The pilots' skill and knowledge were often quite highly taxed in order to successfully complete an RPRV mission.

In the meantime, arguments in favor of the RPRV met with success in the promotion of new programs.

We originally put the test pilot on the ground and an RPRV in the air because the cost and time necessary to develop new research aircraft the conventional way had become prohibitive. Much more ground system, structures, and wind tunnel testing goes into today's aircraft: in 1950, a new aircraft underwent an average of 1200 hours of wind tunnel testing; in 1970, approximately 12,000. The additional wind tunnel test time is due partially to the sophistication of the aircraft, which makes it difficult to duplicate configuration perturbations and flight conditions accurately in the systems, structures, and materials ground tests. The result is that many additional hours of wind tunnel facilities are necessary to give confidence in the data. And the enormous investment involved was discouraging the research community from making bold moves into new technology.

We at Dryden found the RPRV attractive because it built confidence in new technology by demonstrating its capabilities in the real and dynamic environment of flight. Use of RPRV's seemed especially advantageous because it permitted testing to be done at low cost, in quick response to demand, and at no risk to the pilot.

The RPRV has the potential for low cost because of its smaller size, lack of life support systems, and lower requirement for redundant systems. The quick response time and reduced cost result from the elimination of many man-rating tests and from the ability to use simple and modifiable structures. The use of programmable ground-based control systems also provides quick response, as well as flexibility. Finally, hazardous testing is possible because the vehicles may be considered expendable or semiexpendable.

The RPRV differs from the military drone or RPV in that it gives a test pilot exactly the same responsibilities and tasks as if he were sitting in a cockpit on board a research airplane. As in manned flight testing, the pilot has complete responsibility for performing data maneuvers, evaluating vehicle and systems performance, and determining the appropriate action to take in emergencies or if the aircraft does not respond as expected.

The mission of a military RPV, on the other hand, is so distinct that an autopilot can be programed. The craft's aerodynamic performance is accurately defined in extensive wind tunnel and flight testing, and the design of the autopilot is based on these tests. Of course, the flexibility of the autopilot is limited to certain routines, such as cruise, 15° turns, and 30° turns. The controller fine adjusts the autopilot, or several autopilots at once, for he may have a whole formation under his guidance.

In contrast, the RPRV is designed to venture into unexplored engineering territory. It does not perform a stereotyped routine, and part of its mission is to explore the aerodynamic performance of the vehicle. Versatility is necessary for this type of testing, and a pilot is the most versatile system we have. Completely responsible for vehicle control, a pilot can handle only one RPRV at a time. Versatility proved to be a significant selling point for RPRV's.

"Sending more commands up to the vehicle and getting a large quantity of high quality data back constantly with no dropouts or glitches takes broader and more reliable radio-link bands than for an RPV. The RPRV control system would be vulnerable to electronic countermeasures, thus would be unsuitable in a military situation." Experience is always the best teacher. Six years of RPRV flight experience at Dryden have been logged since the words above appeared in Reference (1). The purpose of this lecture is to pass on the lessons learned in RPRV flight testing during that time.

2.0 RPRV FACILITY

The RPRV has in its control loop a powerful ground-based digital computer (Fig 2.0-1). Programing the computer substitutes for the expensive building of new control system design features into the vehicle itself. The computer, located in a ground-based RPRV facility along with a ground cockpit, serves as part of the RPRV simulator as well. Unlike a manned aircraft control system, it can be used in several successive vehicles.

3.0 NASA RPRV PROGRAMS

Figure 3.0-1 illustrates the eight RPRV programs that have been conducted at the Dryden Flight Research Center since 1969. The Big G Parawing and Minisniffer vehicles were operated more like conventional drones and were not considered true RPRV's.

Tables 3.0-1 and 3.0-2 summarize the objectives and characteristics of these RPRV programs. Hardware qualification (Table 3.0-1) signifies the testing of experimental system components intended for use in follow-on programs. From Table 3.0-2, it is obvious that the scope and cost of the RPRV programs vary widely. For example, the very limited scope of the Big G Parawing program permitted its cost to be orders of magnitude less than that of the highly maneuverable aircraft technology (HiMAT) program. The message is that RPRV programs can be designed to match facilities, funds, and personnel to the resources available.

A brief description of each RPRV program follows.

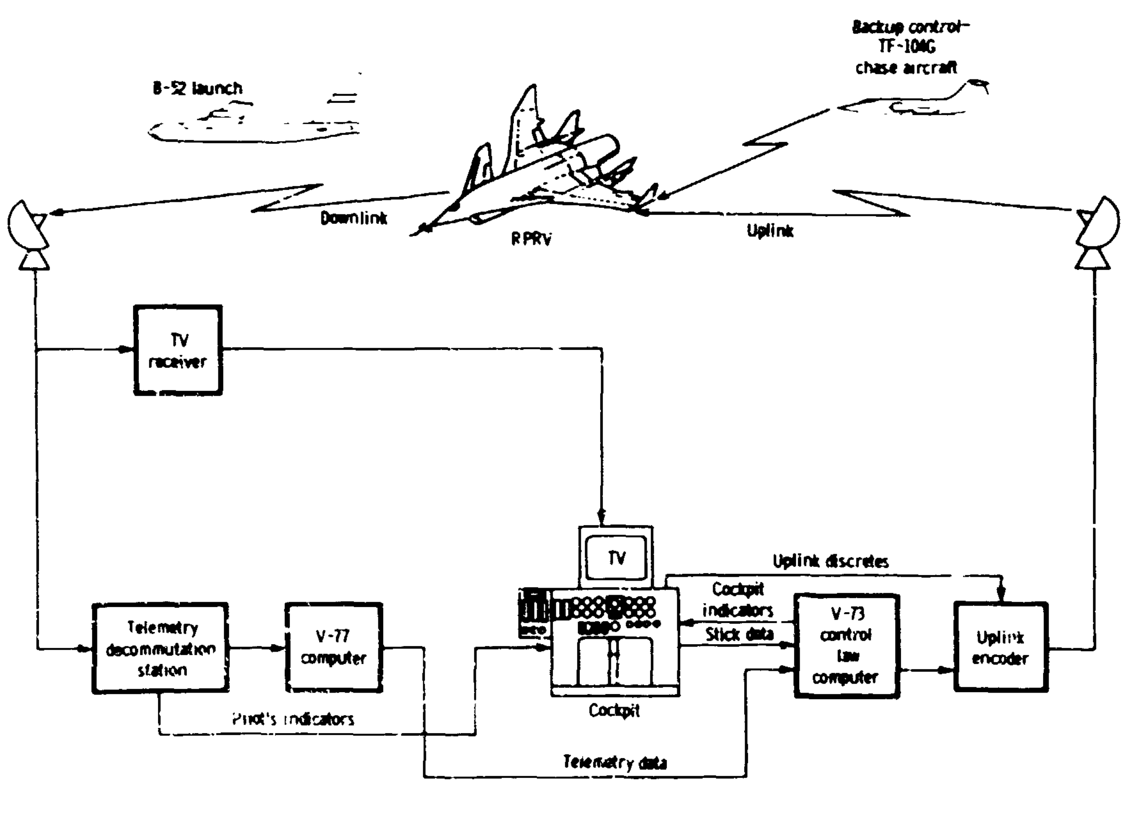

Fig 2.0-1 RPRV control system.

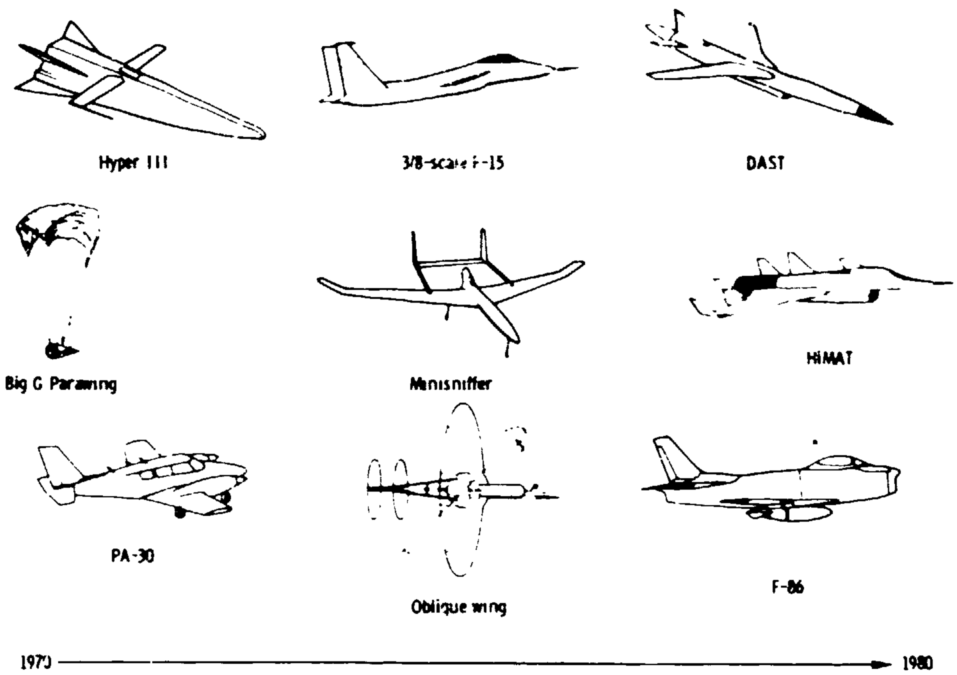

Fig 3.0-1 NASA RPRV programs.

Table 3.0-1 RPRV Program Objectives

RPRV program	Objectives					
	Basic research			Proof of concept		Hardware qualification
	Aerodynamics	Structures	Propulsion	System demonstration	Aircraft configuration	
Big G Parawing	---	---	---	---	X	X
Hyper III	X	---	---	X	X	---
PA-30	---	---	---	X	---	X
3/8-scale F-15	X	---	---	X	X	---
Minisniffer	X	X	X	X	X	X
Oblique wing	X	---	---	X	X	---
DAST[1]	X	X	---	X	X	---
HiMAT[2]	X	X	X	X	X	---
F-86	X	---	---	---	---	---

[1]Drones for aerodynamic and structural testing.
[2]Highly maneuverable aircraft technology.

Table 3.0-2 RPRV Aircraft Information

RPRV vehicle	Propulsion	Parachute equipped*	Type of control system	Vehicle weight, kg	Structure	Number of data parameters	Vehicle cost, dollars
Big G Parawing	None	Yes	Direct, electric	278	Steel tube, aluminum	11	2000 (2 vehicles)
Hyper III	None	Yes	Direct, hydraulic	450	Steel tube, fabric, fiber glass, aluminum sheet	16	5000 (1 vehicle)
PA-30	Propeller	No	Direct, hydraulic, ground computer	1600	Aluminum	35	Available for use
3/8-scale F-15	None	Yes	Direct, hydraulic, ground computer	1100	Wood, foam, fiber glass	77	1,000,000 (2 3 vehicles)
Minisniffer	Propeller	No	Direct, electric, wings leveler	100	Wood, foam, fiber glass, Kevlar	17	100,000 (2 vehicles)
Oblique wing	Ducted propeller	No	Direct, electric	270	Wood, fabric, fiber glass	16	200,000 (1 vehicle)
DAST	Jet	Yes	Direct, hydraulic, autopilot	950	Aluminum, fiber glass	120	500,000 (1 vehicle)
HiMAT	Jet	No	Ground computer, onboard computer, programer, hydraulic	1360	Composite: carbon, Kevlar, aluminum, steel	450	17,300,000 (2 vehicles)
F 86	Jet	No	Direct, hydraulic, SAS[1]	6400	Aluminum	17	Surplus

[1]Stability augmentation system.

3.1 Big G Parawing

The Big G Parawing program was initiated to explore the piloting problems involved in steering a limp-parawing spacecraft configuration to a precision landing on the ground. In 1967, the NASA Johnson Space Center was seriously considering the development of a large version of the Gemini spacecraft that would be capable of returning 12 astronauts to a landing on earth by means of a gliding parachute.

The Big G Parawing program at Dryden had two phases. The first, an RPRV phase, was intended to qualify the parawing system, the structure, and the pilot control system, as well as to measure the loads imposed on an anthropomorphic dummy (Fig 3.1-1) during parawing deployment and ground contact (Ref (2)). In the second phase, the anthropomorphic dummy was to be replaced by a test pilot (Fig 3.1-2) to explore the piloting problems involved in steering the craft to a landing while looking through a viewing port similar to that in the Gemini spacecraft. Forty successful RPRV flights were conducted from 3000 meter drops to precision landings by a visual pilot (a pilot watching from the ground) using a model airplane transmitter. The second phase of the program was cancelled when NASA decided to abandon the drop concept in favor of the horizontal landing (shuttle) concept.

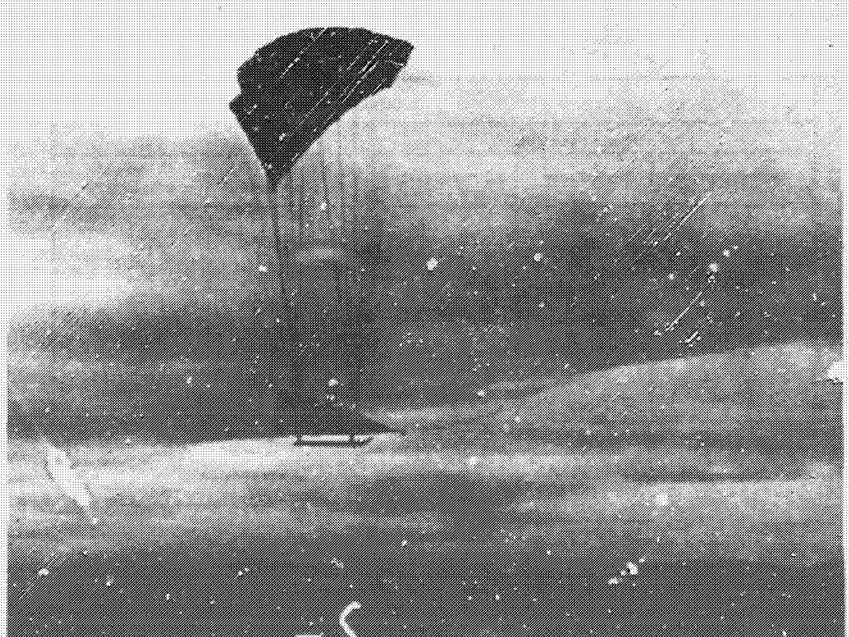

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Fig 3.1-1 Parawing test vehicle.

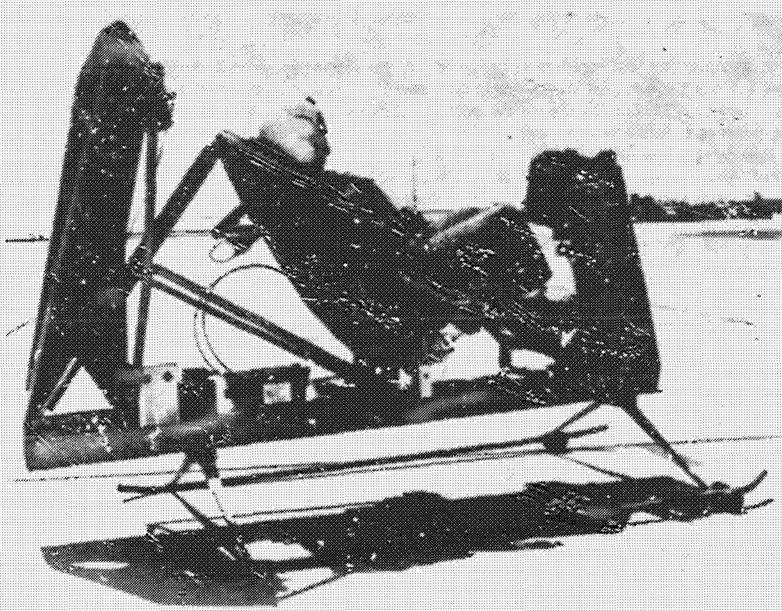

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Fig 3.1-2 RPRV test vehicle with anthropomorphic dummy.

3.2 Hyper III

The objective of the Hyper III program (Ref (3)) was to acquire flight data and investigate the unaugmented subsonic flying characteristics of a reentry spacecraft capable of flight at hypersonic speeds and at high lift-to-drag (L/D) ratios (L/D = 3). The spacecraft utilized a deployable single-piece skewed wing (Fig 3.2-1). The vehicle was towed by helicopter to 3000 meters, launched, and then flown down to about 200 meters by a pilot using instrument flight rules from a ground cockpit. At that altitude control was transferred to a visual pilot, who conducted an unpowered flare and landing. The biggest operational problem occurred in towed flight; the Hyper III had a tendency to make S turns below and behind the helicopter. The IFR pilot found that by experimenting he could damp out these turns by referring to the attitude indicator in the ground cockpit and making the appropriate control inputs. The rest of the flight went according to plan as practiced on the simulator for the IFR pilot and as practiced on speed-scaled radio-control models by the visual pilot.

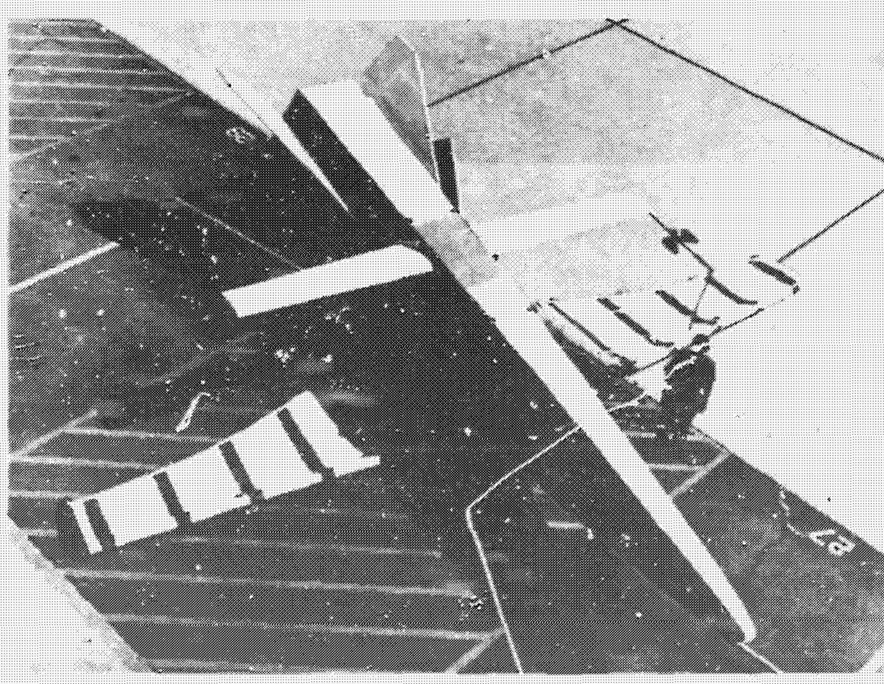

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Fig 3.2-1 Hyper III with skewed wing installed and experimental folding flex-wing on ground.

3.3 PA-30

The control system for the light twin-engine PA-30 airplane (Fig 3.3-1) was originally developed at the NASA Dryden Flight Research Center for experimental control systems work. The controls on the left seat are rigged electrically for fly-by-wire control through a hydraulic control system. The control system commanded from the right seat is the basic mechanical system, and it employs a safety cutout system so the safety pilot can take immediate control of the aircraft at any time. The downlink data transmission system in the aircraft made it natural to install a control system uplink and a TV downlink for RPRV development and research. The PA-30 has been used to develop several RPRV operational concepts, including the ground-based computer control system (Ref (4)) and automatic backup landing system for the HiMAT vehicle. The aircraft is never flown without a safety pilot on board.

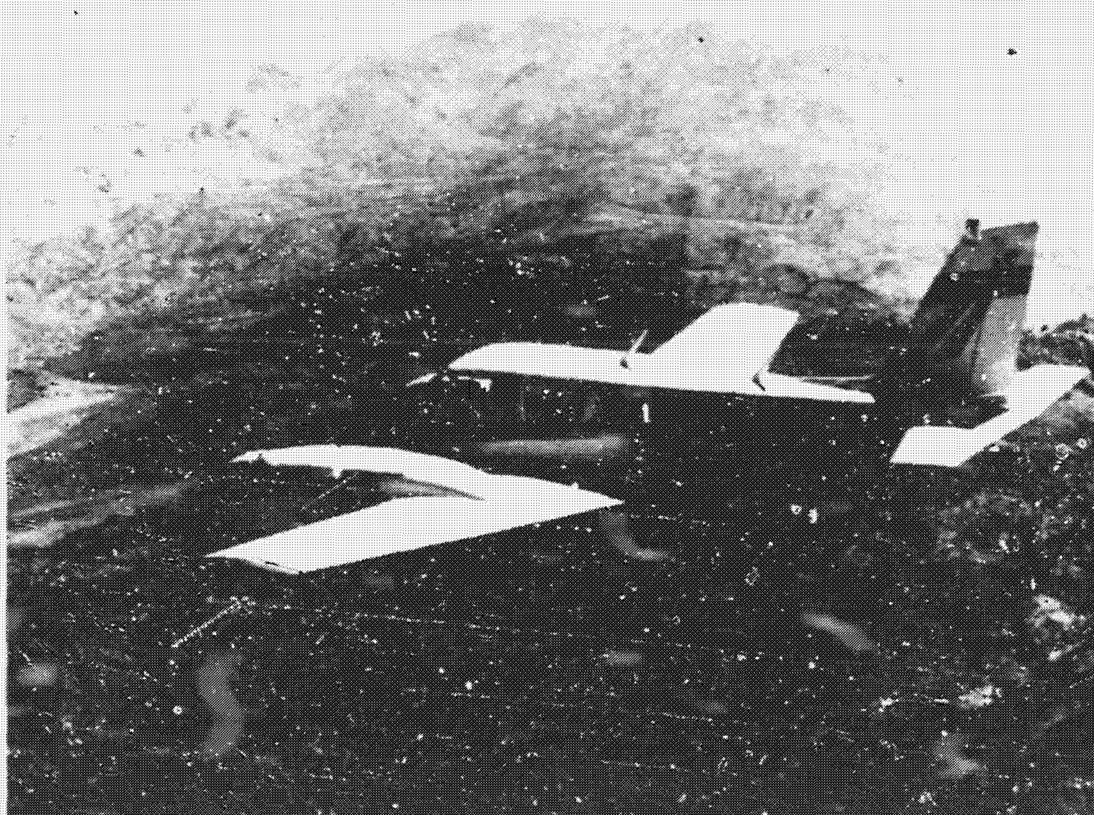

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Fig 3.3-1 PA-30 airplane used for RPRV development and simulation.

3.4 3/8-Scale F-15

The objective of the 3/8-scale F-15 program (Fig 3.4-1) was to explore the aerodynamic and control system characteristics of the F-15 aircraft in spins and high-angle-of-attack flight. The program was designed to make maximum use of existing equipment at the Dryden Flight Research Center. For example, hydraulic, gyro, and telemetry systems available from the retired lifting body programs were used for the aircraft's control systems. The proportional uplink then being used by researchers for transmitting radar data to pilot director instruments on board aircraft for curved instrument landing system (ILS) experiments was incorporated in the 3/8-scale F-15 aircraft for uplink control. Ground data processing computers were also pressed into service for the programmable ground-based control system. A general purpose simulator cockpit being used for stability and control studies was utilized for the RPRV pilot control station. A mid-air recovery system (MARS) Firebee II parachute system was utilized for vehicle recovery during the first flights. Later flights utilized horizontal landing for recovery.

A contract was let to construct three models to contain the NASA-supplied equipment.

The complete familiarity of the NASA crew with the aircraft equipment, combined with easy access to the equipment and uncrowded space inside the vehicle to work on the equipment made the operation of this vehicle relatively straightforward. In total, 35 launches were made from 14,000 meters. Data were acquired to explore the effects of different nose shapes and aerodynamic devices as well as the effects of various control system schemes on vehicle spin characteristics (Refs (5) to (7)).

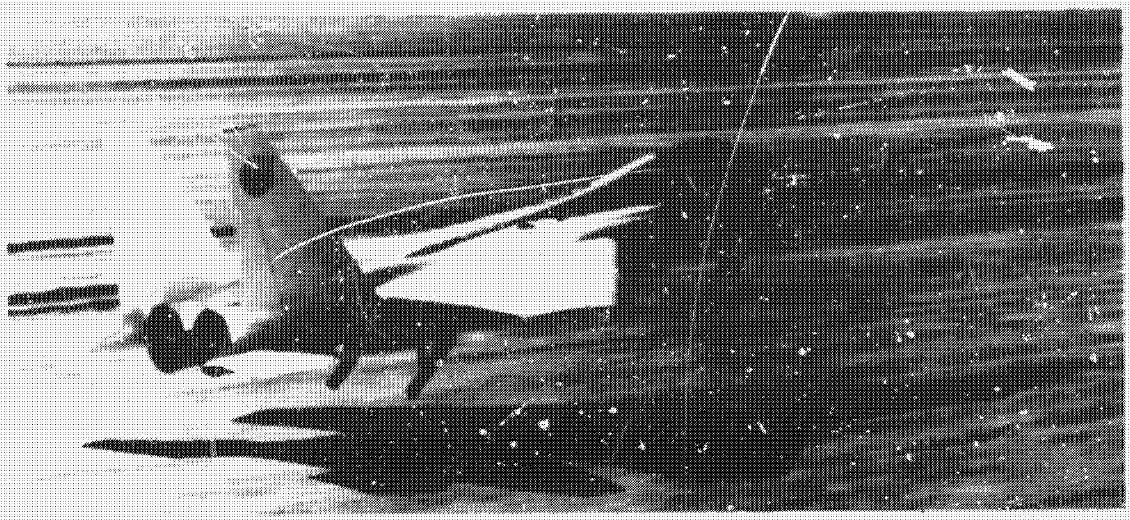

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Fig 3.4-1 3/8-scale F-15 being guided to horizontal landing by RPRV TV link.

3.5 Minisniffer

The Minisniffer program, which began in 1975, was initiated to develop a small unmanned atmospheric survey aircraft capable of sensing turbulence and of measuring both natural and man-made atmospheric pollutants at altitudes up to 27,000 meters (Ref (8)). The vehicle was to be able to fly at low speeds and to be able to maneuver precisely at stratospheric altitudes to conduct atmospheric research on a routine basis. The design missions called for the vehicle to carry an 11 kilogram air sampler to 21,000 meters and to cruise at that altitude for an hour over a range of about 320 kilometers, or to glide back from a 27,000 meter climb.

An essential element in the Minisniffer concept was the development of a reciprocating monopropellent hydrazine engine to drive a large, slowly turning propeller. The NASA Johnson Space Center took responsibility for the development of the hydrazine engine: Dryden was responsible for the development of the complete system. While Johnson worked on the hydrazine engine (Fig 3.5-1), Dryden built the Minisniffer with conventional gasoline propulsion for early flights (Fig 3.5-2) so work could proceed on the vehicle's aerodynamics, structure, and guidance and control systems.

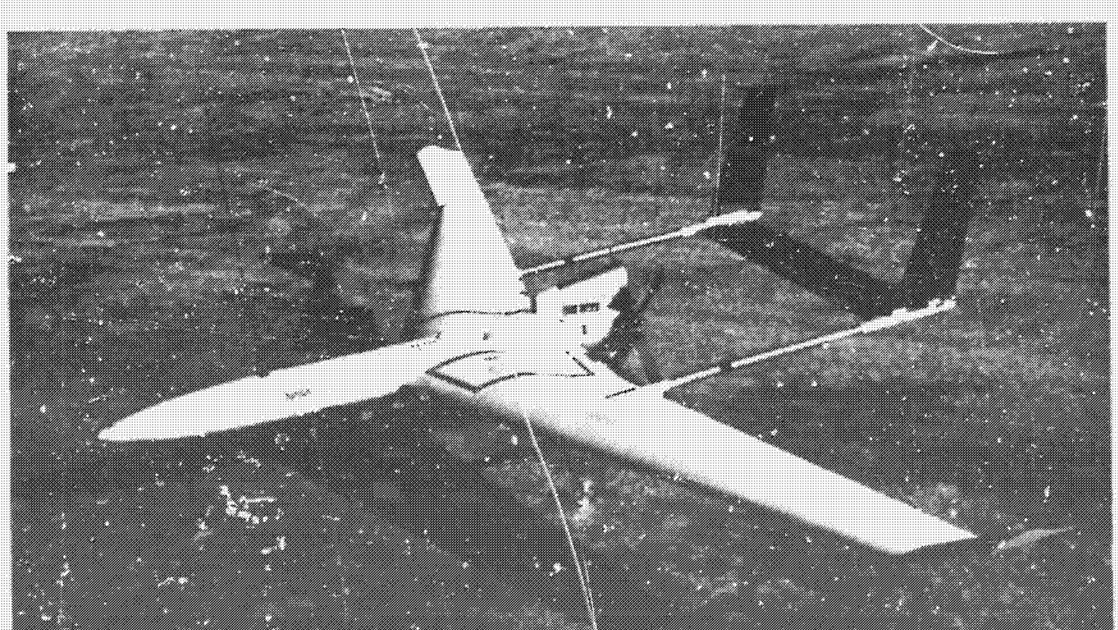

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Fig 3.5-1 Minisniffer with hydrazine propulsion.

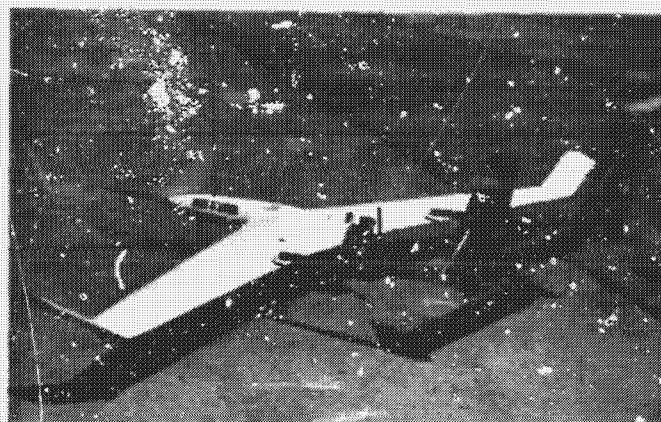

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Fig 3.5-2 Minisniffer with gasoline propulsion.

The first flight tests were conducted with model aircraft radio control systems. Actuators were doubled up when greater hinge moments demanded it. Later, a special lightweight radio control system characterized by longevity and high reliability at high altitudes was developed. A simple wings-leveler system was found to be necessary in turbulent air. A yaw-rate gyro drove the rudders that served as the wings-leveler system. The system worked through dihedral effect at all altitudes and was designed to serve as a Dutch-roll yaw damper at altitudes above 15,200 meters. The hydrazine engine was demonstrated in flight to 6000 meters with a fixed-pitch propeller. However, program funds were not available to develop the variable-pitch propeller needed to climb to higher altitudes.

A later study with the NASA Jet Propulsion Laboratory showed that the Minisniffer could perform well in the rarified carbon dioxide atmosphere of the planet Mars. The 38 percent earth gravity on Mars makes less horsepower necessary for flight, giving the hydrazine-propelled Minisniffer a theoretical 8000 kilometer range over the Mars surface. Use of a Minisniffer-type vehicle for Mars exploration is still under consideration.

3.6 Oblique Wing

The NASA Ames Research Center decided to investigate the oblique wing concept primarily because of its potential for enhancing transonic cruise efficiency. The idea is to position the straight-across wing at right angles to the fuselage for takeoff and landing and to swing one wingtip forward for cruise flight. Wind tunnel data acquired in the Ames wind tunnels indicated that an oblique wing configuration might have lower drag than, for example, variable sweep wings as well as have lower sonic-boom potential on the ground track.

After a radio-controlled model was built and flown by Robert T. Jones at Ames, the Ames engineers devised an RPRV program to further demonstrate the configuration. A contract was awarded for the design and development of a subsonic-only oblique-wing RPRV. The vehicle was to be capable of flight with no tail or with minimum tail so the aircraft could be made as compact as possible. A duct around the propeller was part of the overall structural and aerodynamic scheme.

The resulting vehicle (Fig 3.6-1) was turned over to Dryden for flight testing. The flight test program was short and simple, with a small team of Ames and Dryden personnel working together to

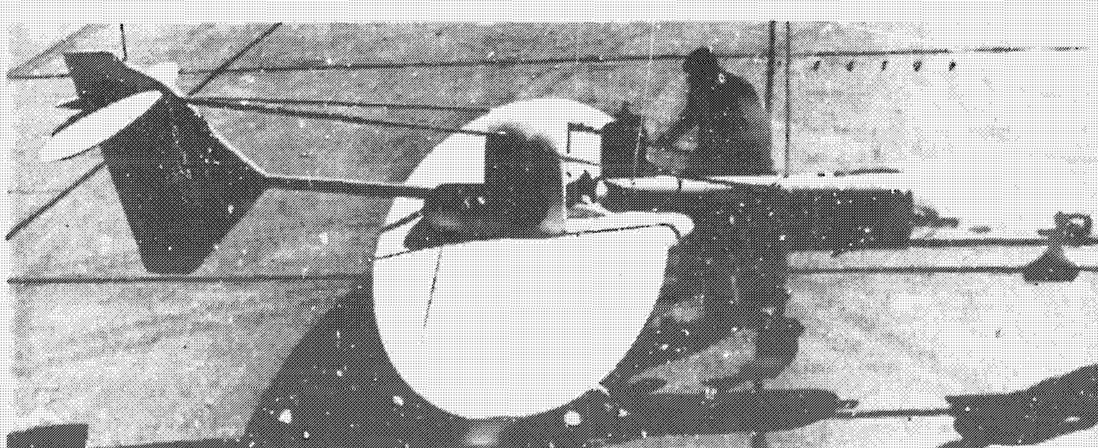

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Fig 3.6-1 Oblique wing RPRV.

acquire stability and control data (Ref (9)). Three flights were made, and the wing was placed at angles up to 45°. The same model airplane uplink system used in the early phases of the Minisniffer program was used to control the vehicle; however, bigger electric actuators were required.

3.7 Drones for aerodynamic and structural testing

The drones for aerodynamic and structural testing (DAST) program was designed to test large-scale models of wings designed for high efficiency cruise in flight at transonic speeds in combination with experimental flutter suppression systems. The high fuselage fineness ratio and supersonic capability of the Firebee II drone made an ideal testbed for these experimental wings. A Firebee II drone loaned to NASA by the Air Force was equipped with an experimental wing (Fig 3.7-1) at the NASA Langley Research Center. The drone was modified at the NASA Dryden Flight Research Center to incorporate an RPRV flight control system in which the test pilot has direct control over the maneuvers performed with the aircraft. The DAST I wing has a Whitcomb supercritical airfoil section and incorporates small aileron-like surfaces controlled by an electronic-hydraulic flutter suppression system. The DAST I vehicle is intended to be flown beyond the flutter boundary of the wing in order to demonstrate the effectiveness of the flutter suppression system. A parachute system is available to recover the aircraft in case of an unpredicted failure of the wing.

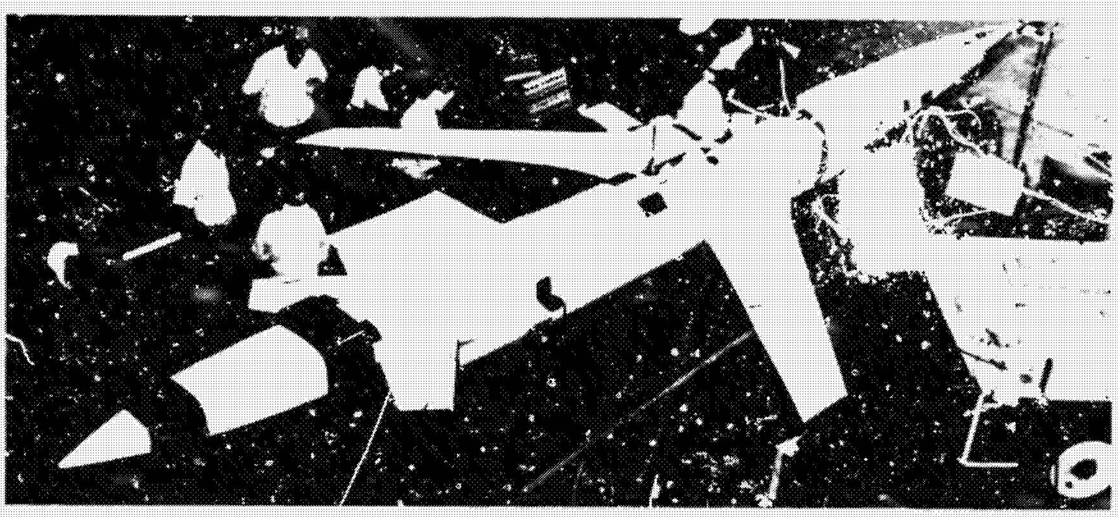

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Fig 3.7-1 DAST RPRV with experimental wing.

3.8 Highly maneuverable aircraft technology

The HiMAT project utilizes a 44 percent-scale model of a 7700 kilogram fighter. It has a wingspan of just over 4.6 meters and a length of 6.9 meters. It was designed to be air launched from a B-52 airplane, and it should be capable of speeds in excess of Mach 1.5. Two of the research vehicles have been built.

The HiMAT RPRV (Fig 3.8-1) is an experimental vehicle in which a synergistic approach is being used to accelerate the development of a new fighter aircraft (Refs (10) to (12)). This approach involves combining many new high-risk technologies into one vehicle to provide information on the interaction between the systems. One of the technological advances incorporated in the HiMAT vehicle is the composite material used for approximately 30 percent of its construction. In addition to weight savings, the composite material allows the wings and canards to be aeroelastically tailored for increased maneuverability and performance. Aeroelastic tailoring uses the unique directional properties of the graphite composite materials to control bending and twisting under aerodynamic loading. In the process of manufacturing the composite, the fibers in the material are oriented in the direction that results in favorable wing twisting as aerodynamic loading increases. The HiMAT's composite wing can be compared roughly to a wood veneer that is stiff in one direction but pliable in another. Under g stresses, the composite structure deforms enough to give the vehicle about 10 percent additional maneuvering capability, even in very tight turns

The HiMAT control system is of the digital fly-by-wire type which is lighter in weight than a conventional control system. Pilot commands are fed via telemetry to an onboard computer, which sends electronic commands to the flight control surfaces. Another technology being tested is an integrated propulsion system. Instead of a conventional hydromechanical system, this system uses a digital computer to control the aircraft's entire propulsion system. The HiMAT vehicle is powered by a J58 jet engine. The research vehicle also incorporates active control technology that causes the flight control system to provide the aircraft's basic stability. Use of this technology saves weight and increases performance, since the size of the stabilizing surfaces can be reduced.

One of the design requirements for the HiMAT vehicle was that no single failure should permit the loss of the vehicle. Because of this design philosophy, dual systems were incorporated throughout the aircraft. This applied to the microprocessor computers, hydraulic and electric systems, servoactuators, uplink receivers and antennas, downlink transmitters, and antennas.

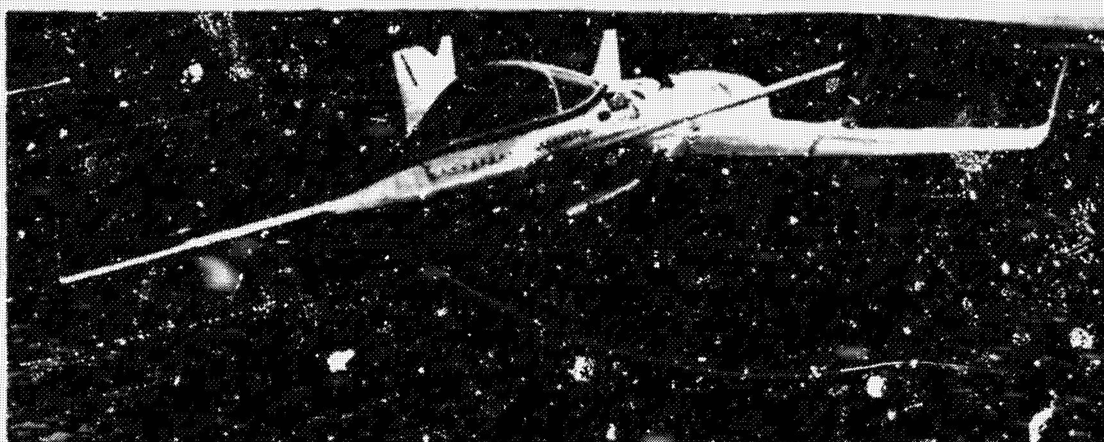

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Fig 3.8-1 HiMAT RPRV after landing on dry lake.

3.9 F-86

Dryden has been participating in a joint program with the Federal Aviation Administration (FAA) to minimize or eliminate the hazard to small aircraft of encountering the wingtip vortices generated by large jet aircraft. In this program, an instrumented manned T-37 jet trainer at Dryden had been used to probe the wake of a B-747 aircraft at altitude. It was deemed too dangerous to encounter these vortices close to the ground.

The Naval Weapons Center at China Lake was then asked to participate in tests using one of their F-86 RPV's (Fig 3.9-1). The Navy had developed an RPV target system around surplus F-86 fighter aircraft, using a system very similar to the one used for the 3/8-scale F-15 system. A surplus F-86 ground simulator is used in conjunction with a transmitted TV image, and the pilot controls the F-86 directly, with full aerobatic maneuvering capability.

A flight test program was then developed in which the F-86 RPRV was used to probe the visible wake of a B-747 (Fig 3.9-2) during landing and takeoff. Twenty-four encounters with B-747 wingtip vortices were made with the F-86 RPRV. The RPRV pilot prevented the F-86 from contacting the ground several times through his ability to respond quickly to aircraft upsets; the value of the RPRV technique was demonstrated through these tests alone, because the data could not have been acquired in any other way.

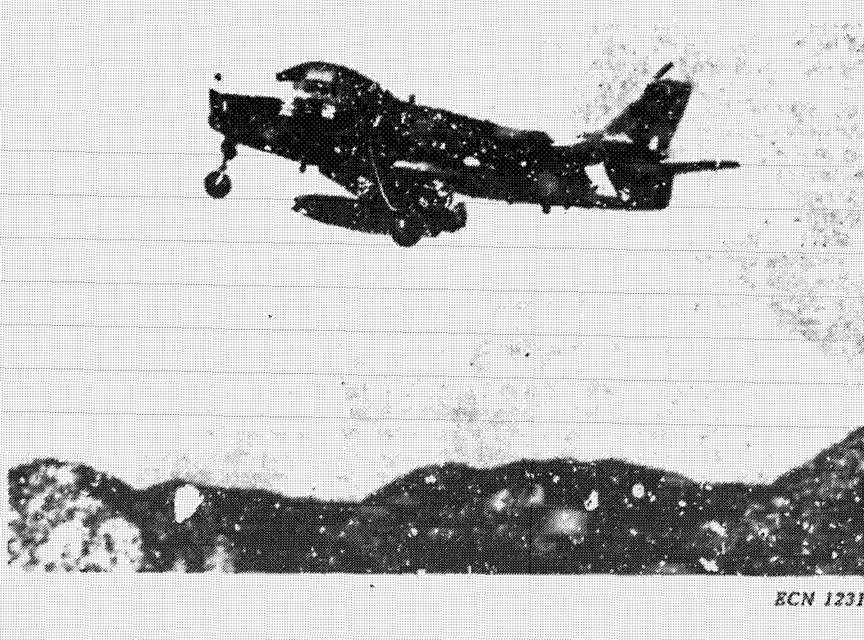

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Fig 3.9-1 F-86 RPV used to probe wingtip vortices generated by B-747.

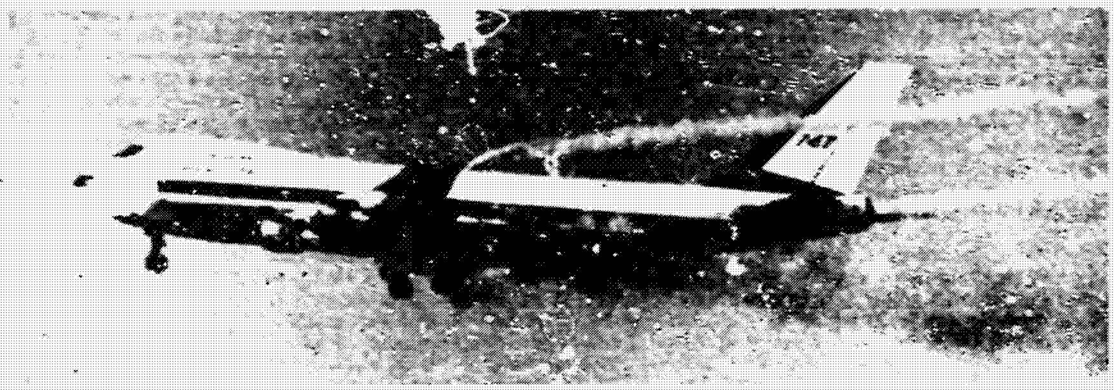

Fig 3.9-2 B-747 with wingtip vortices made visible by smoke generators.

4.0 RPRV OPERATIONAL FEATURES

Table 4.0-1 summarizes some of the operational features of the RPRV programs conducted at the Dryden Flight Research Center. The ground cockpit with downlinked TV is the most popular piloting technique. Piloting through visual contact with the radio-controlled airplane has been used only in small programs, where low cost and simplicity are of primary importance.

Table 4.0-1 RPRV Operational Features

RPRV vehicle	Launch technique	Recovery technique	Piloting technique
Big G Parawing	Helicopter drop	Gliding parachute	Visual, stationary
Hyper III	Helicopter tow	Horizontal landing skids, parachute backup	Ground cockpit, visual, stationary
PA-30	Horizontal takeoff	Horizontal landing	Ground cockpit (TV), safety pilot
3/8-scale F-15	B-52 drop	MARS and horizontal landing	Ground cockpit (TV)
Minisniffer	Horizontal takeoff	Horizontal landing	Visual car chase, radar, TV
Oblique wing	Horizontal takeoff	Horizontal landing	Ground cockpit (TV)
DAST	B-52 drop	MARS	Ground cockpit, F-104 chase
HiMAT	B-52 drop	Horizontal landing	Ground cockpit (TV), F-104 chase, automatic
F-86	Horizontal takeoff	Horizontal landing	Ground cockpit (TV), T-33 chase

The B-52 airplane is the vehicle currently being used to launch RPRV aircraft at Dryden. Although it is much larger than necessary to carry RPRV's aloft, it has proven to be cost effective in the manner in which it is being used: a low launch frequency (one 2-hour flight per month for the DAST and HiMAT programs) reduces its operating costs to a small proportion of the total program operating cost.

The midair recovery system was used for the 3/8-scale F-15 and DAST RPRV's. This recovery technique was chosen because the Edwards Air Force Base 6514th Test Squadron was willing and able to furnish a helicopter and crew to capture the RPRV's in the parachute MARS mode. A high degree of crew proficiency and skill is necessary to make consistently successful captures. The Air Force MARS crew maintains proficiency by practicing with dummy payloads and by retrieving Air Force drones and cruise missiles. It would not be cost effective for NASA to maintain such a capability for its limited number of RPRV's.

5.0 SAFETY CONSIDERATIONS

Each RPRV program has its own set of circumstances and approaches to safety. There are some basic guidelines that are consistently followed, however. The most fundamental of these is that the safety of the people in the launch aircraft and on the ground has priority over the preservation of the RPRV.

The ground rules set up for a particular RPRV program may specify that the vehicle is expendable or semiexpendable. These guidelines are followed when the acquisition of data or flight results under conditions that put the vehicle at risk is considered more important than the loss of the vehicle. Under these circumstances, if all of the data objectives are achieved in one flight and the vehicle crashes at the end of the flight, the program is still considered successful. The ground rules set up for the oblique wing program were similar to this. However, all three planned flights were flown without vehicle loss.

The ground rules for the oblique wing were set up in this way because personnel safety and data objectives did not require vehicle recovery and because the program's cost and time constraints did not permit the precautions that would ensure the safety of the vehicle. Personnel safety could be ensured because the oblique wing was flown within the airspace over Edwards Air Force Base, an airspace from which commercial air traffic is excluded. Further, there are no homes or businesses in the region where the flight tests were conducted. The vehicle was at risk because it had no autopilot functions and was basically spirally unstable. It had no redundant systems whatsoever, not even a backup visual pilot in case the IFR pilot in the cockpit using downlink TV lost control of the vehicle. Thus, many system failures would necessarily have resulted in a crash. However, as planned, the lack of redundancy permitted the flight test program to be conducted at low cost and in a timely manner.

In direct contrast, nothing was spared to avoid the loss of the HiMAT vehicle. The design philosophy for HiMAT was "No single failure shall cause the loss of the vehicle." This project ground rule, of course, did not take priority over personnel safety. The foremost safety concern in any of the B-52 launch operations is the safety of the B-52 air crew in a possible collision between the RPRV and the B-52 after launch. Launch dynamics are carefully analyzed for every air-launch vehicle. Much thought goes into the operational schemes to ensure a clean launch, especially in the case of unstable vehicles, and precautions vary from locking the controls to installing jettisonable RPRV nose ballast.

6.0 INSTRUMENT FLIGHT RULES PILOT TRAINING

6.1 Cockpit characteristics

For RPRV's, most vehicle control is done from a ground cockpit not unlike a ground-based simulator cockpit. The cockpit contains aircraft controls and IFR instruments that are tied into the RPRV through a data link and tracking system. Ground computers are used with the more sophisticated RPRV's (Fig 2.0-1). The cockpit is equipped with a TV screen only if horizontal takeoffs or landings are planned.

At Dryden, RPRV's are usually flown from cockpits located in the so-called RPRV facility, an area in the main building. However, on occasion cockpits have also been installed in vans or trailers near the flight testing in order to shorten the radio range for landing and takeoff operations. The Hyper III and oblique wing cockpits were portable and used at the remote landing sites (Fig 6.1-1).

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Fig 6.1-1 Portable outdoor Hyper III cockpit with IFR and visual pilots in place.

6.2 Ground support crew

A flight test engineer often sits next to the cockpit (Fig 6.2-1) to assist the pilot in reading checklists, timing maneuvers, and setting up vehicle control configurations through the ground computer systems. Making up a third member of the team is the flight controller in the Dryden control room. The flight controller is in charge of the operation, and all of the operational information is available to him on plot boards, including vehicle telemetry data and radar tracking information. The controller is always in direct contact with the RPRV pilot, by hard wire if the cockpit is in the RPRV facility or by radio if the cockpit is at a remote site.

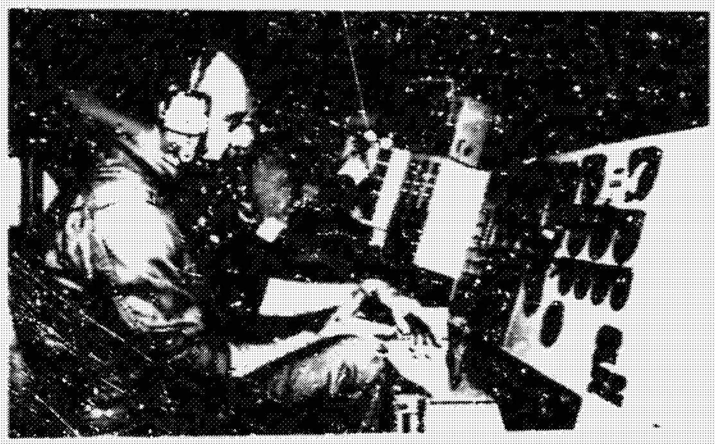

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Fig 6.2-1 HiMAT RPRV cockpit with pilot and flight test engineer at flight stations.

6.3 Iron bird simulation

A simulator cockpit identical to the RPRV cockpit is used for pilot training. In the case of the HiMAT vehicle, the signals from the actual RPRV cockpit are fed into a general purpose simulation computer. At some times, signals are fed into the actual (full-scale) aircraft, which is sitting in an adjacent hangar. When the actual airplane is hooked into the simulation (iron bird simulation), the flight crew, pilot, flight test engineer, and controller develop procedures and techniques for verifying aircraft computer software programing before flight to detect possible system failures during flight.

6.4 Training for ground controlled approaches

The controller and sometimes the flight test engineer may assume the responsibilities of a ground controlled approach (GCA) controller to steer the pilot through a landing pattern. Many hours of practice on the simulator involving the RPRV pilot, flight test engineer, and flight controller are necessary to develop flight plans, practice research maneuvers, and develop emergency procedures.

7.0 VISUAL PILOT TRAINING

Radio-controlled model investigations have been conducted at the Dryden Flight Research Center with models weighing less than 18 kilograms for the preliminary investigation of advanced concepts (Refs (13) to (15)), but they were not considered RPRV projects in and of themselves. Radio-controlled models did play a major support role, however, in providing the visual pilot with training for the larger scale Hyper III and Minisniffer RPRV's. The so-called mother ship (Fig 7.0-1), a large 3 meter span model

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Fig 7.0-1 Radio-controlled mother ship, a model used to launch experimental models and to develop RPRV techniques.

airplane originally used to launch model lifting bodies, was equipped with a vertical gyro for pitch and roll control, an airspeed indicator, and a radar beacon to develop control transfer techniques between the visual pilot and the IFR pilot.

A second radio-controlled model, a 1/6-scale model of the Piper III that was weight scaled for speed (body lengths per second), provided an excellent training aid for the visual pilot, who had the task of landing the relatively low lift-to-drag-ratio (L/D ≈ 5), unpowered, 456 kilogram, 18.7 meter Piper III RPRV.

A similar 44 percent-scale model was used for visual pilot training for the Minisniffer RPRV.

8.0 LESSONS LEARNED IN RPRV PROGRAMS

8.1 Program planning

By definition, the purpose of the RPRV's is to acquire experimental data. It is important that research engineers spell out the data objectives for the program in as much detail as possible early in the program. The vehicle design and program operational scheme should be selected that achieve these objectives in the most cost effective way. Any revisions of the program to match available personnel, facilities, and funds should be made only after a preliminary vehicle design and operational scheme have been selected. This type of activity is also important in developing manned research aircraft. However, the impact on RPRV programs is greater because decisions on operational techniques (air launch versus ground launch, parachute recovery versus horizontal landings, and so forth) are highly dependent on research objectives.

8.2 Flexibility: an advantage of RPRV programs

More easily than most flight testing, an RPRV flight test program can be tailored to match available personnel, facilities, and funds. This is possible because one RPRV program may require only the simplest of vehicles (one that uses a drone-type control system, for example), whereas another RPRV program may require a much more elaborate vehicle, such as one with a control system that requires several control systems people, for the data objectives to be met. Almost every RPRV program at Dryden was an experiment in operations and was designed to match the available operational personnel and equipment.

8.3 Staffing

Assigning an operations engineer and crew chief early in the vehicle design phase prevents the loss of much time later in the program. These are the people who must make the vehicle work later, and they will make sure it will if they are able to make their needs known early in the vehicle design phase. This is true for any research aircraft, but it is no less important for RPRV's.

8.4 Simulation: a vital tool in RPRV programs

Because the IFR RPRV pilot lacks the motion cues, visibility cues, and sound cues that a test pilot sitting in a manned aircraft cockpit enjoys, he must work much harder to extract information from the cockpit instruments. Simulation is vital to RPRV programs for both systems development and pilot training. The more complex an RPRV is, the more simulation time is necessary. RPRV flights are usually planned in such a way as to extract as much data as possible from each flight because of the higher risk of vehicle loss. As a consequence, every minute of flight time is used to produce as much data as possible during the flight. Precise training for the maneuvers on a simulator is necessary to give this data return.

A small RPRV program such as that for the Minisniffer made use of a very simple and minimal simulation. However, the simulation proved to be very valuable in developing the wings-leveler yaw-damping system and in providing pilot training. Pilot training was especially important in that only a turn-rate and airspeed indicator could be used in yaw-damper-off data maneuvers.

8.5 Advantages of modular approach

Probably the most time-consuming effort in an RPRV program is the design, development, and ground testing of the special or newly developed systems required due to the small size of the RPRV. If known systems can be used, a structure can be sized and designed to utilize them much more quickly than if special systems must be developed to fit a particular structure. (The minimum size of the structure of a manned vehicle is dictated by the cockpit and life support systems.) A good analogy is wind tunnel testing. The wind tunnel itself, the wind tunnel measuring systems, and the data reduction systems are to wind tunnel personnel what already established RPRV module systems are to flight test personnel. The aircraft structure is analogous to wind tunnel test models.

Building an RPRV that has all-new systems as well as a new structure is similar to building a new wind tunnel test facility as well as a wind tunnel test model. The time necessary to accomplish the task increases accordingly.

8.6 The synergistic approach

The HiMAT is the RPRV in which the synergistic approach has been used. As of this writing, three flights have been conducted with the HiMAT vehicle. More flights must be made before the full potential of the concept can be demonstrated, with all systems working together to result in greater vehicle performance than can be provided by the sum of the individual systems.

9.0 ADVANTAGES AND DISADVANTAGES OF RPRV'S

In recommending the RPRV approach to a flight test program, it is easy to list the advantages of the approach over manned flight testing, such as the ability to take higher risks in flight and to eliminate man-rating tests. The RPRV approach has the potential for reducing costs. In the real world, however, some of these benefits may fail to materialize. For example, many systems actually become manrated because of the danger of collision with manned launch aircraft and the fear of losing the RPRV.

The advantages and disadvantages of the RPRV approach to flight testing may be summarized as follows.

9.1 Potential advantages

The potential advantages of the RPRV approach are lower program cost because of smaller vehicle size, the elimination of manrated tests, and the elimination of life-support systems. Further, higher risks can be taken in RPRV's than in manned aircraft.

9.2 Disadvantages

The disadvantages of the RPRV approach are as follows. Higher program costs and time delays are often experienced as a result of the need to develop special miniature systems to fit into the limited space of the small aircraft. The limited space in small aircraft requires systems to be stacked, making work access during flight operations difficult. As program planning proceeds, very often extra redundancy or operating restrictions are imposed to ensure the safety of the people on the ground and in the launch aircraft. The up- and downlink communications are vulnerable to outside radio interference, which jeopardizes mission success. A large operational effort is required for crew training, the operation of tracking ranges and safety chase aircraft, and the preparation of the RPRV ground facility for each flight. In addition, line-of-sight range limitations restrict high-speed RPRV operations.

The successful operation of an RPRV requires a highly disciplined operational team and sometimes a very elaborate operational network. Many manhours must be expended in training exercises, dry runs, and briefings to ensure successful operation. As a result, the operational cost per flight of an RPRV can and very often does exceed that for an equivalent manned aircraft. However, if high data output per flight can be planned and if risk restrictions can be relaxed, RPRV operations can be most effective.

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